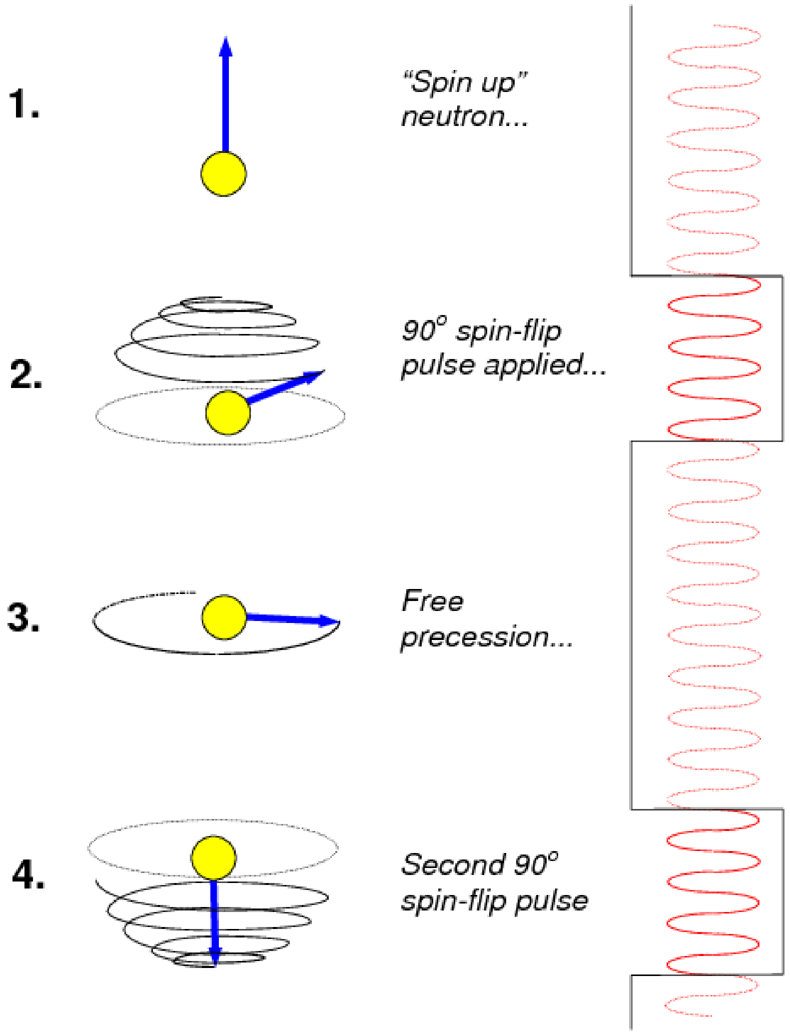
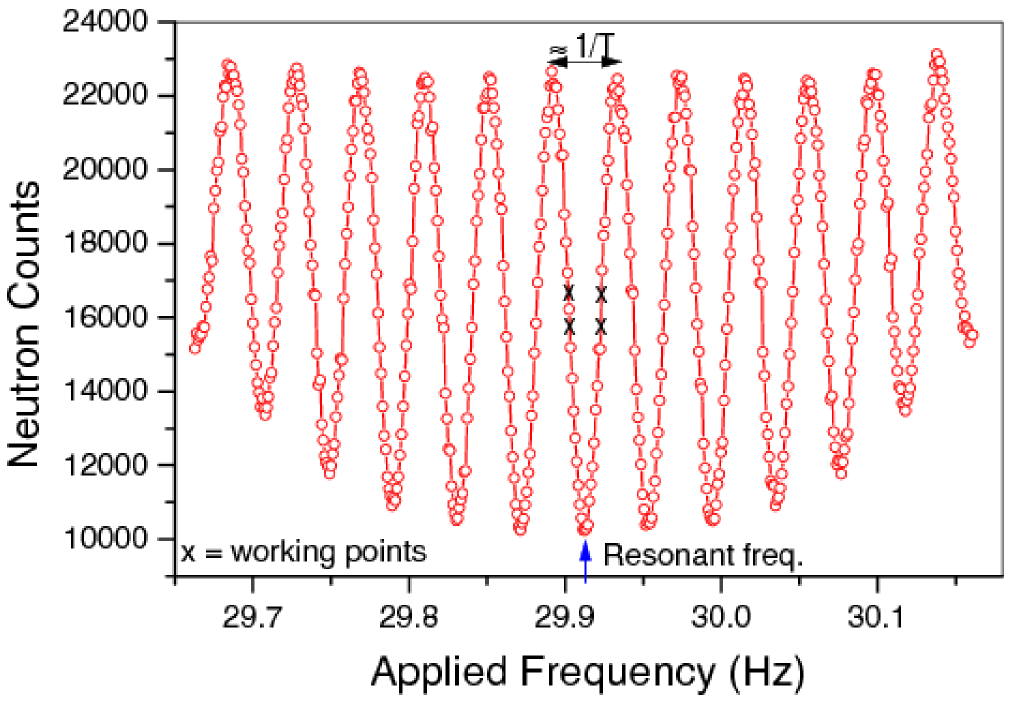
Towards TUCAN's Search for the Neutron Electric Dipole Moment

Wolfgang Schreyer for the TUCAN collaboration

How to measure the neutron electric dipole moment

Ramsey's method of separated oscillating fields





$$\sigma_d = \frac{\hbar}{2E\alpha T\sqrt{N}}$$

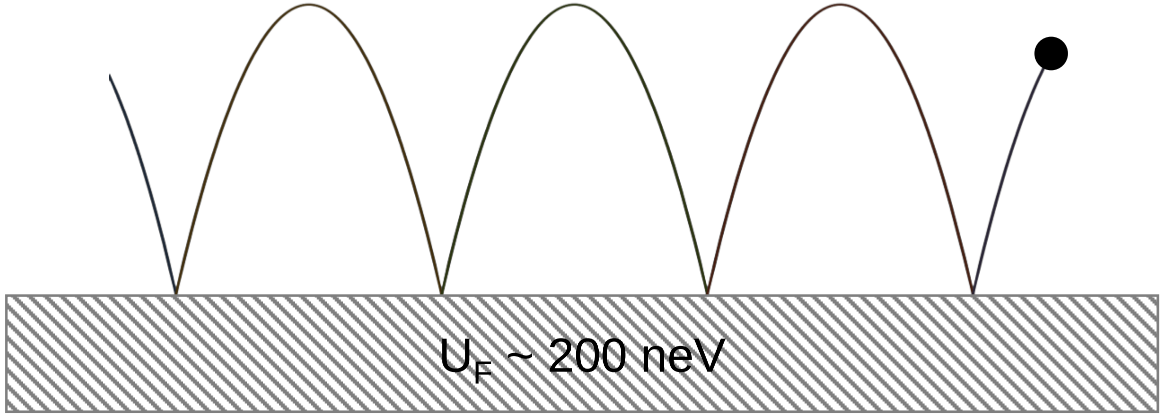
Current best limit: $d < 3 \cdot 10^{-26}\ ecm$

Requires extremely stable magnetic field!

10.1016/j.nima.2013.10.005

Ultracold neutrons are the tool of choice

- $E_n < U_F \sim 200\ \mathrm{neV}$
- $m_n g = 102.5\ \mathrm{neV/m}$
- $\mu_n = \pm 60.3\ \mathrm{neV/T}$



$$\sigma_d = \frac{\hbar}{2E\alpha T\sqrt{N}}$$

$\alpha \sim 0.95$ $\quad$ $\mathrm{T} \sim 100\ \mathrm{s}$ $\quad$ $\mathrm{N} \sim 10/\mathrm{cm}^3$

Stronger UCN sources are the key to higher sensitivity!

TUCAN’s goals

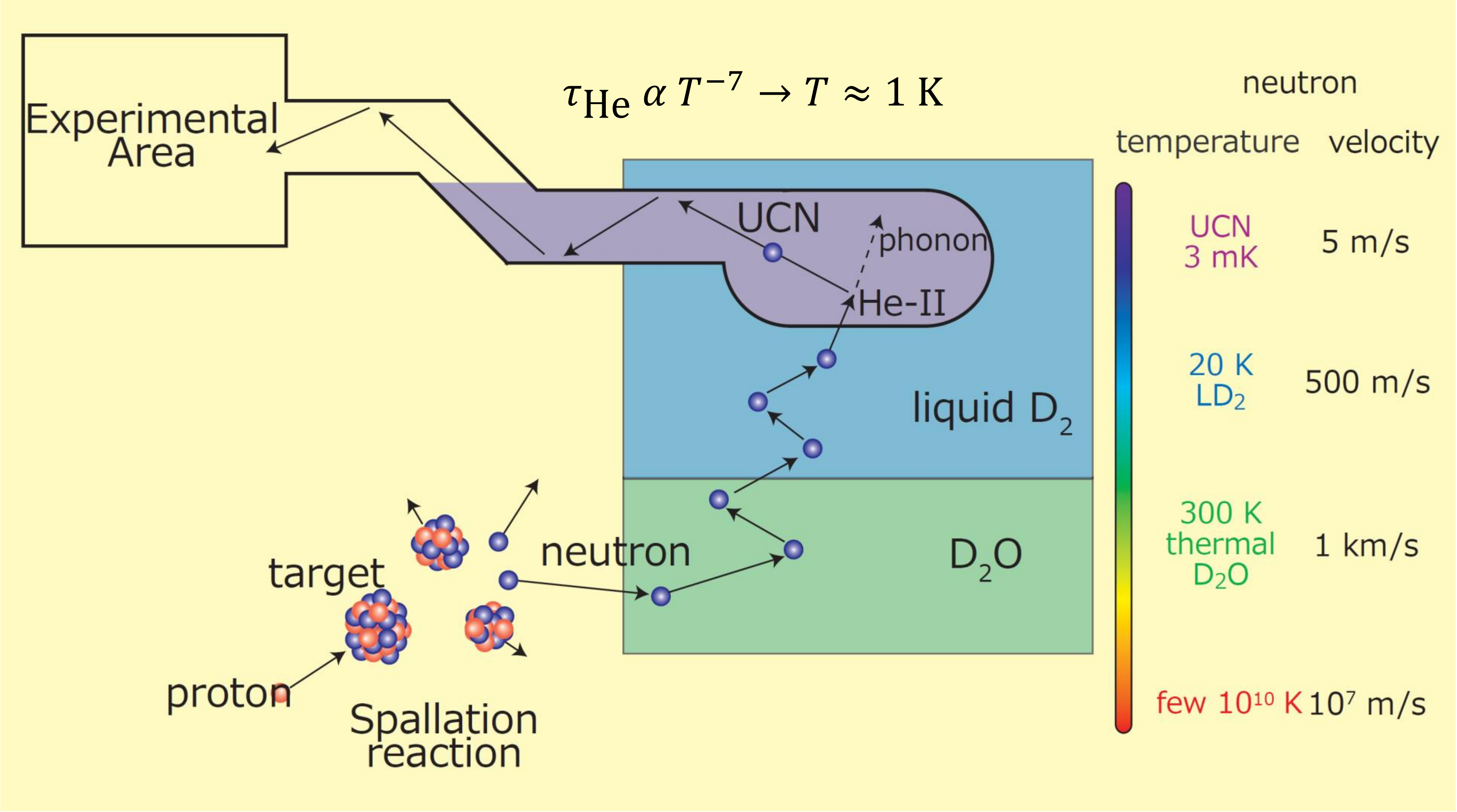
TRIUMF Ultracold Advanced Neutron source

- Reach an nEDM sensitivity of 10^{-27} ecm
- Build the strongest UCN source in the world
- Second UCN port as a user facility

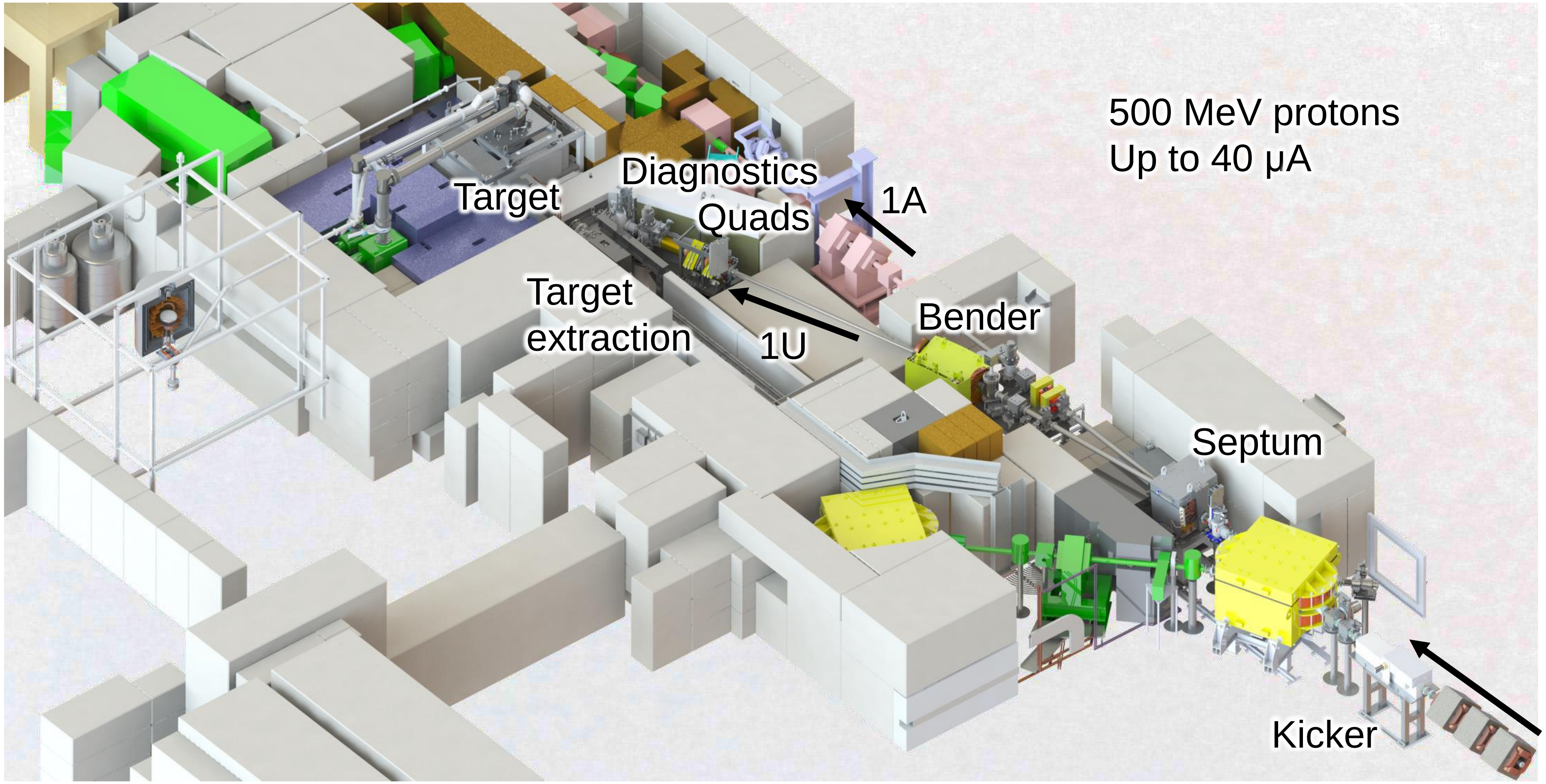
TRIUMF
KEK
RCNP
THE UNIVERSITY OF WINNIPEG
UNIVERSITY OF MANITOBA
UBC THE UNIVERSITY OF BRITISH COLUMBIA
SFU SIMON FRASER UNIVERSITY ENGAGING THE WORLD
NAGOYA UNIVERSITY
UNBC UNIVERSITY OF NORTHERN BRITISH COLUMBIA

The path to a new high-intensity UCN source

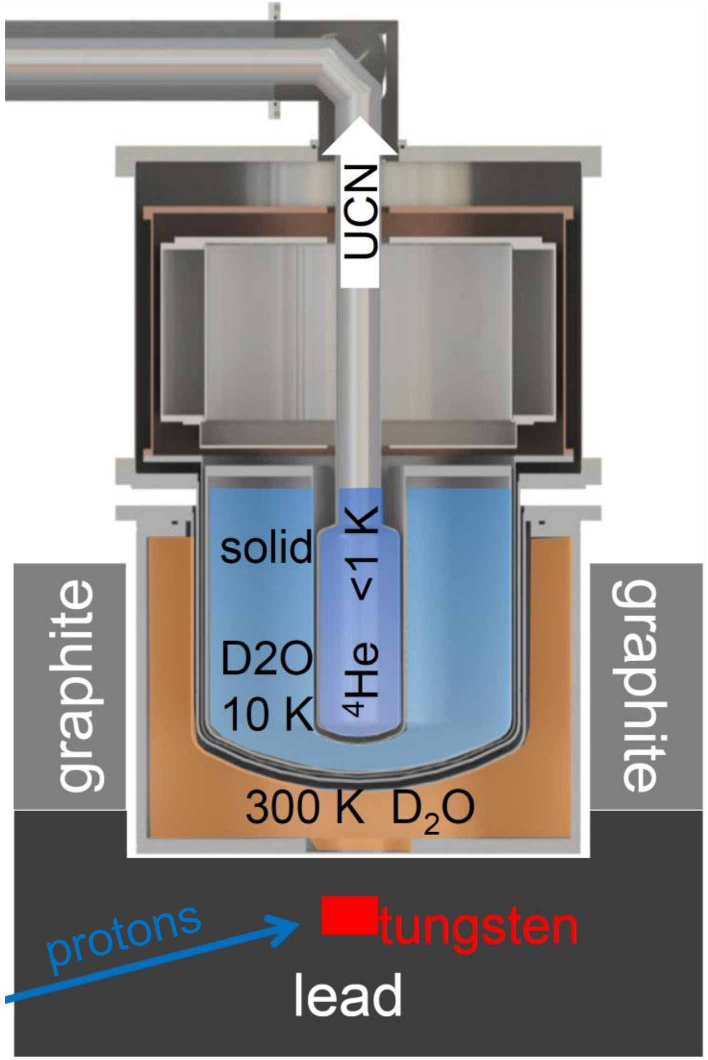
A superthermal spallation source for UCN using superfluid helium

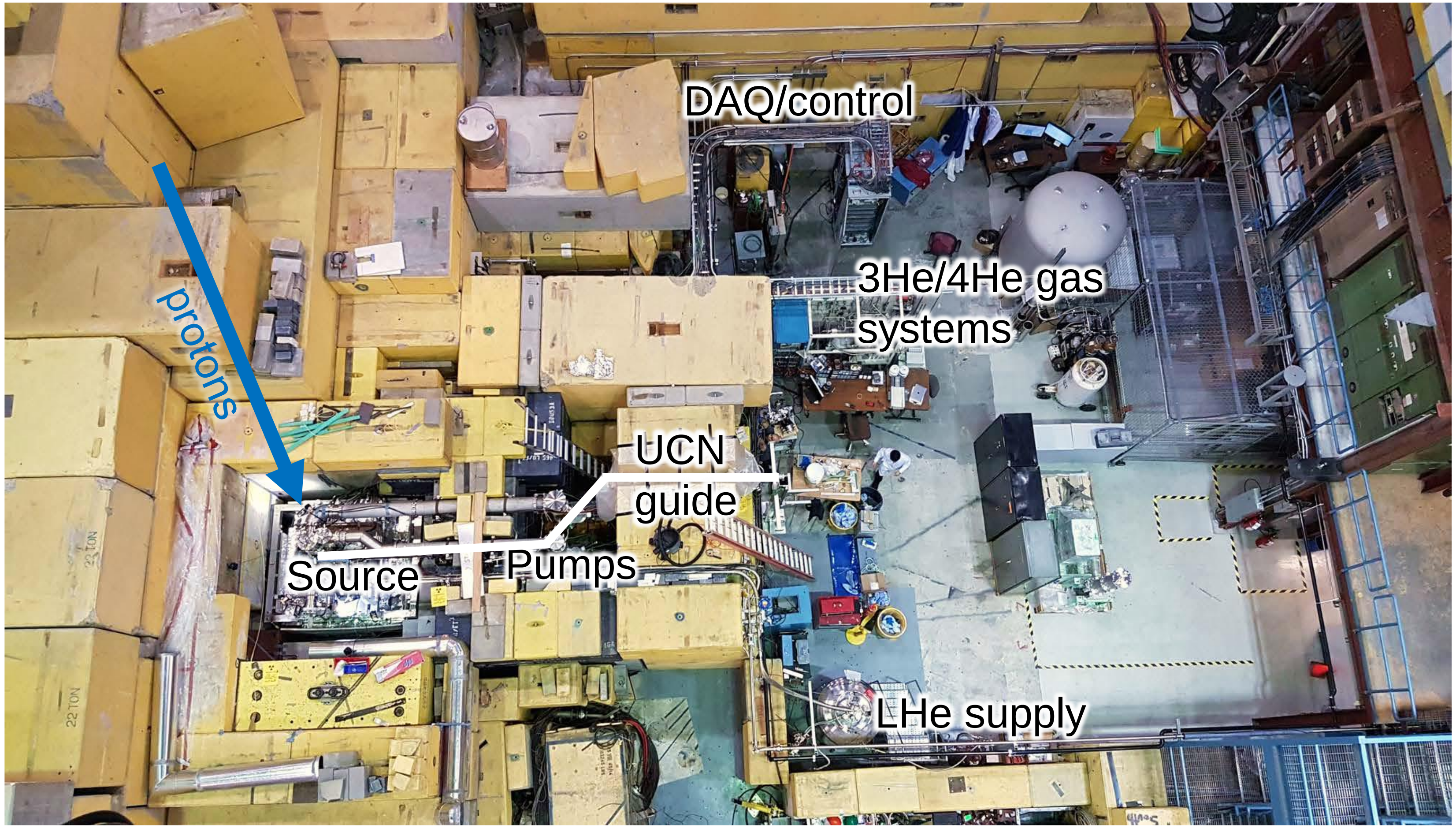


A new beamline and spallation target at TRIUMF

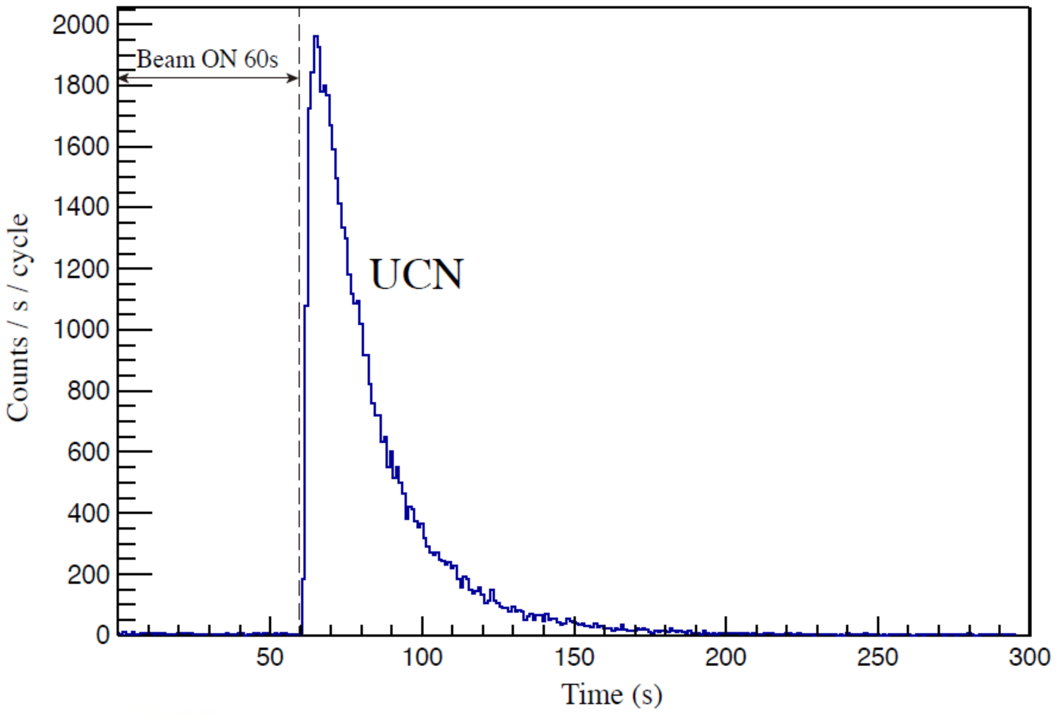


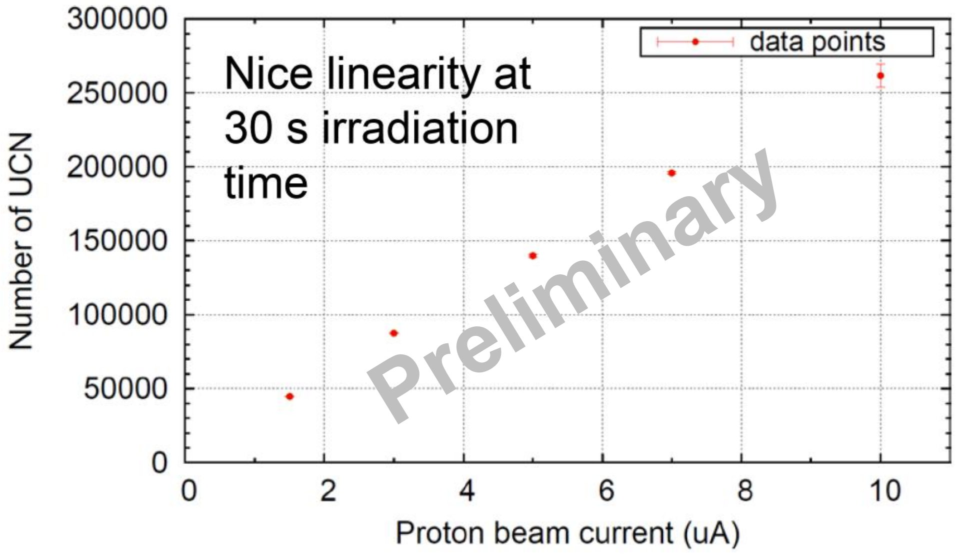
Prototype source (developed in Japan) installed 2017





Nov. 2017: First UCN produced in Canada



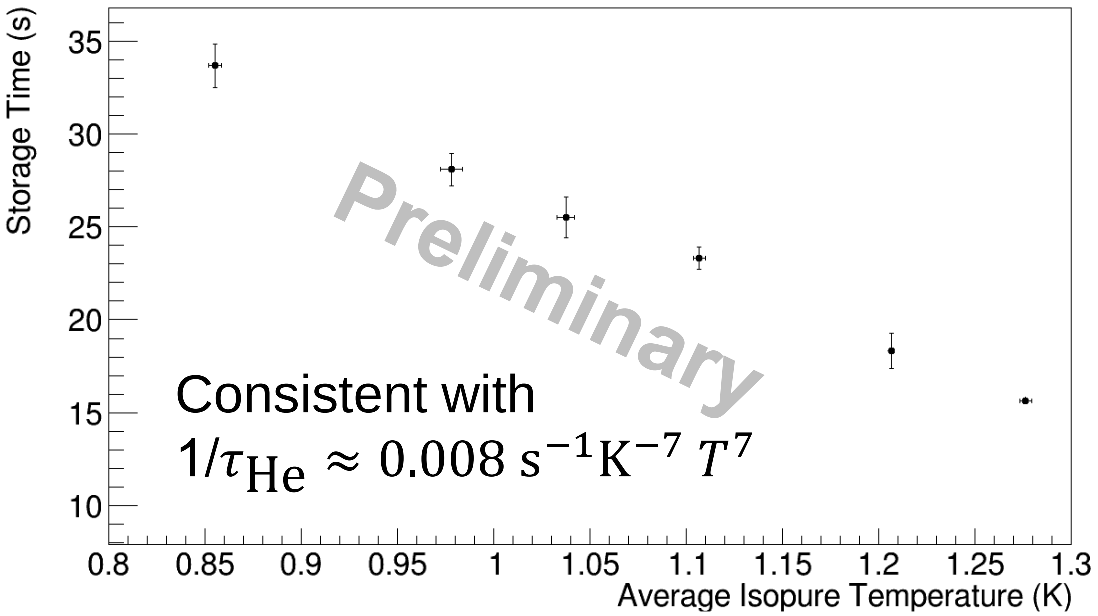


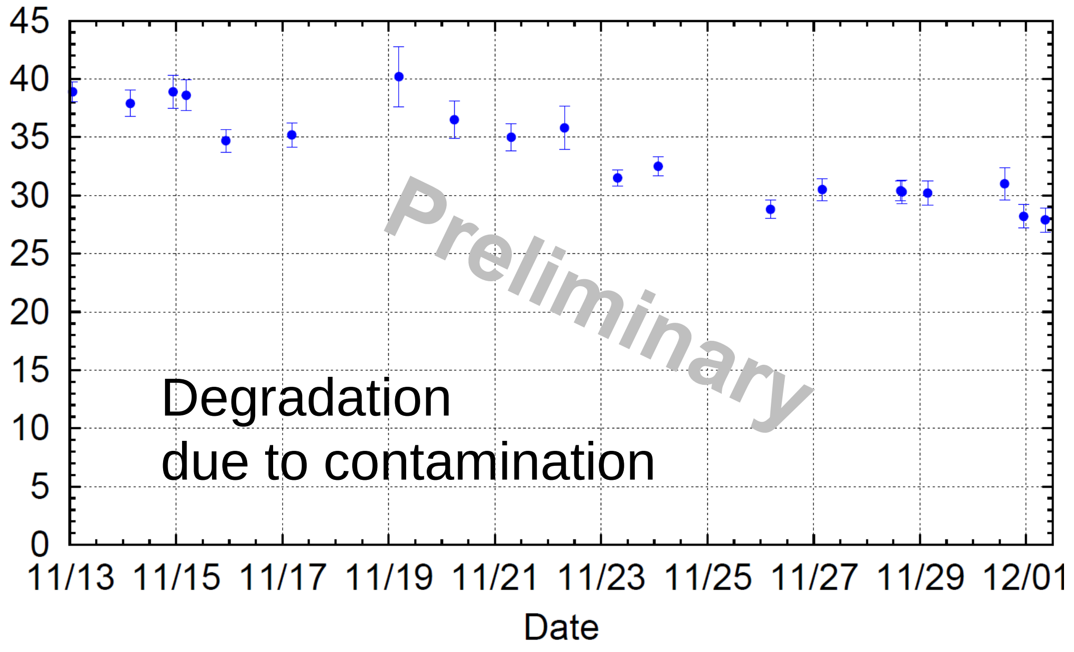
Measurement program

- Characterization of source
- Benchmark simulations (MCNP, PENTrack) github.com/wschreyer/PENTrack.git
- Guide-transmission measurements

40000 UCN @ 1uA
Max 300000 @ 10uA

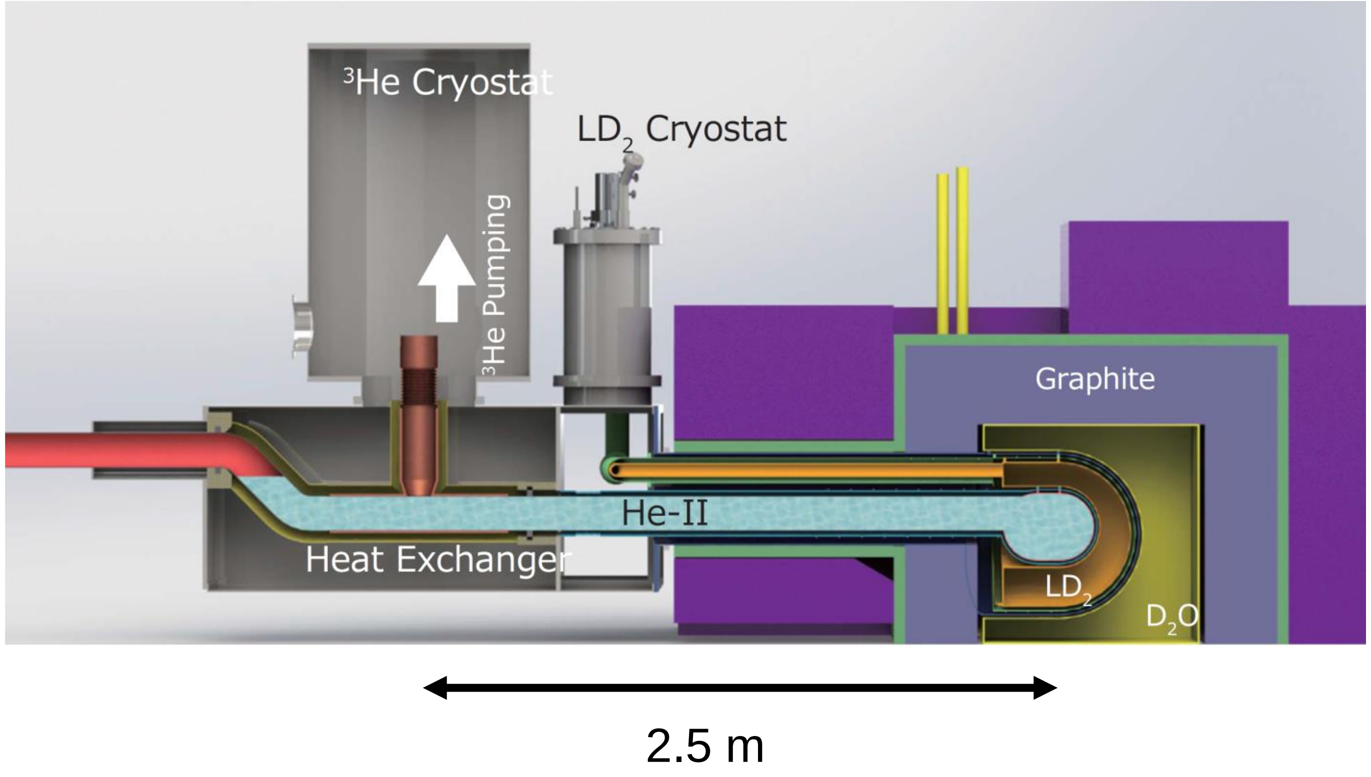
Characterization of prototype source





Available UCN = Production rate x Storage time

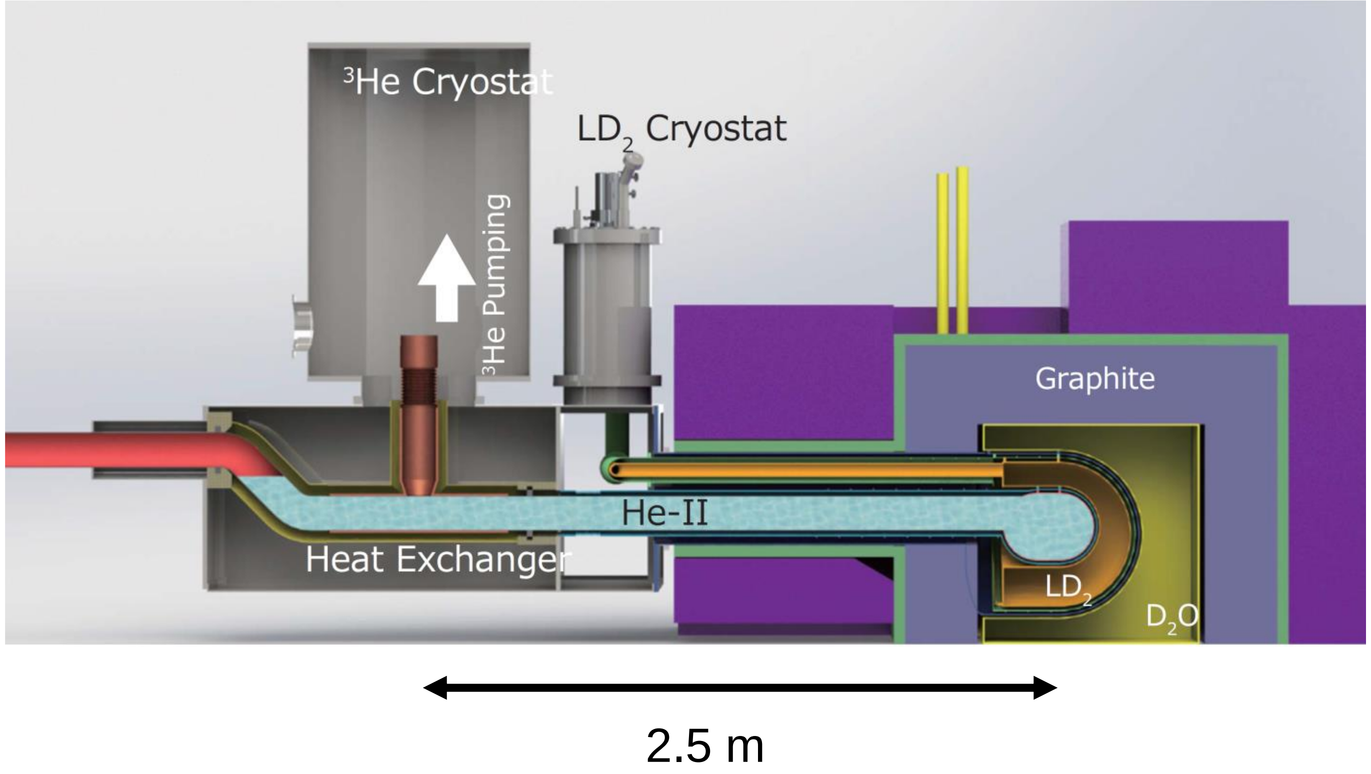
Upgraded source is being designed right now



Planned improvements

- Beam current: 1 μA → 40 μA
- Production volume: 8 L → 34 L
- Cold moderator: sD_2O → LD_2
- Production rate: 20000/s → 2.5×10^7/s
- Cooling power: 0.3 W → 10 W
- He-II temperature: 0.85 K → 1.10 K
- Separation foil

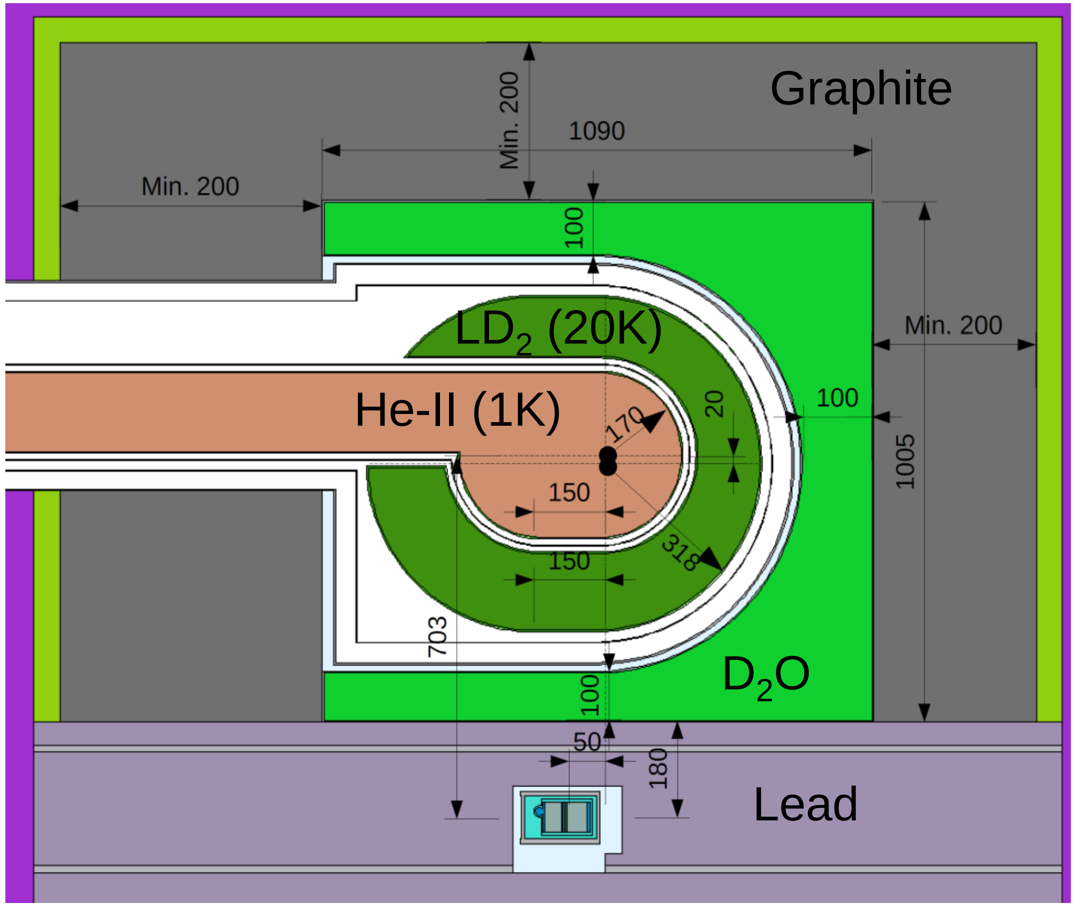
Upgraded source is being designed right now



Crucial features

- Heat transport in He-II and heat exchanger
  - Detailed calculations
  - Measurements at KEK
- LD_2 safety
- UCN production/heat load
  - Heavily optimized with MCNP

New source is heavily optimized



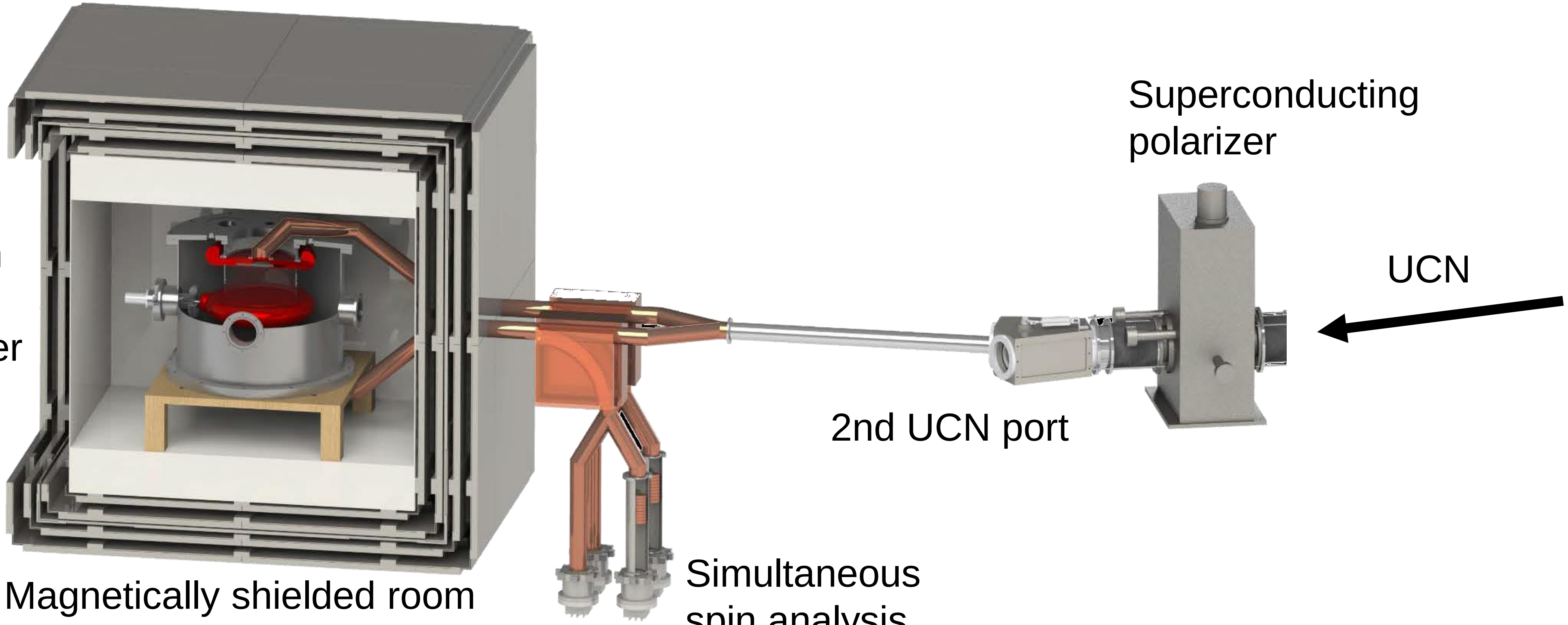
Target

Multidimensional optimization

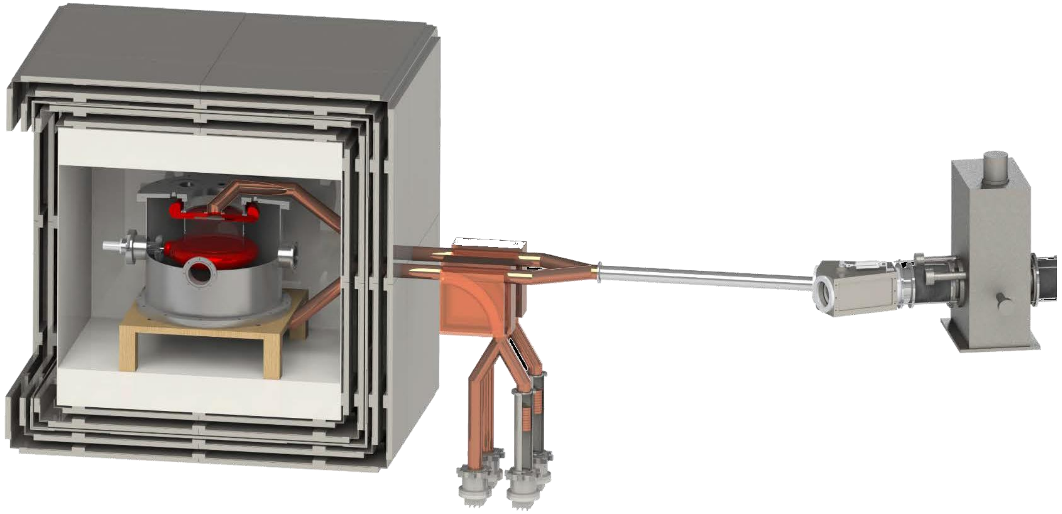
- Detailed MCNP model
- Vary geometry
- Optimize UCN production and heat load
- Using SciPy and ComputeCanada

What can we achieve?

Developments for nEDM



Statistical sensitivity of 10^{-27} *e*cm reached after ~300 beam days

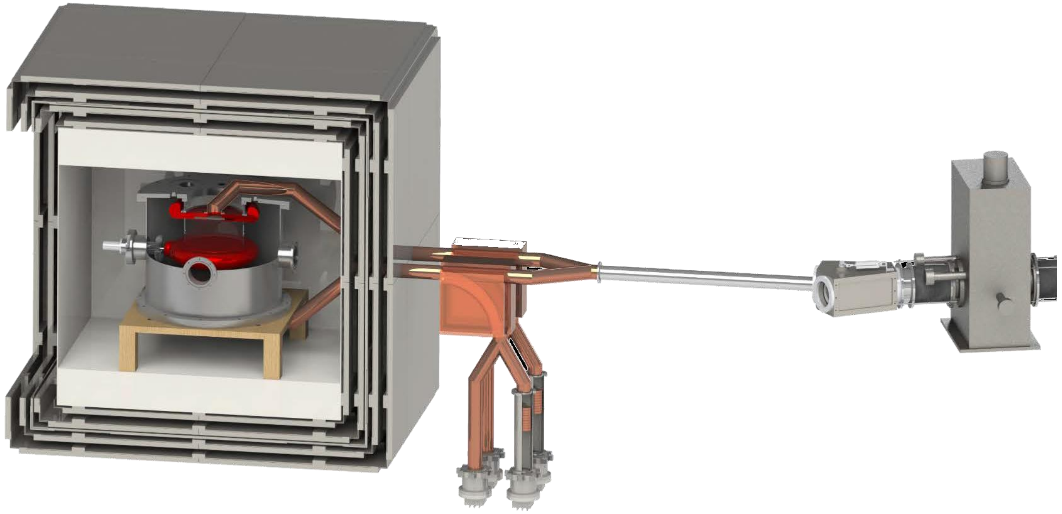


Many effects taken into account

$$\sigma_d = \frac{\hbar}{2E\alpha T\sqrt{N}}$$

- E = 12 kV/cm
- α_0 = 0.95 with typical polarization losses
- T = 120 s
- N = 200/cm^3
  - UCN production from MCNP
  - Detailed model of heat transport and UCN storage time in source
  - UCN transport with typical losses

Statistical sensitivity of 10^{-27} *e*cm reached after ~300 beam days



Crucial parameters

- UCN guides
  - Transmission measurements at PSI and prototype source
  - Many simulation studies with PENTrack
  - Coating facility at U Winnipeg
- Cell size
- Systematic effects
  - Magnetic field homogeneity/stability
  - Simulation studies with PENTrack

Conclusions

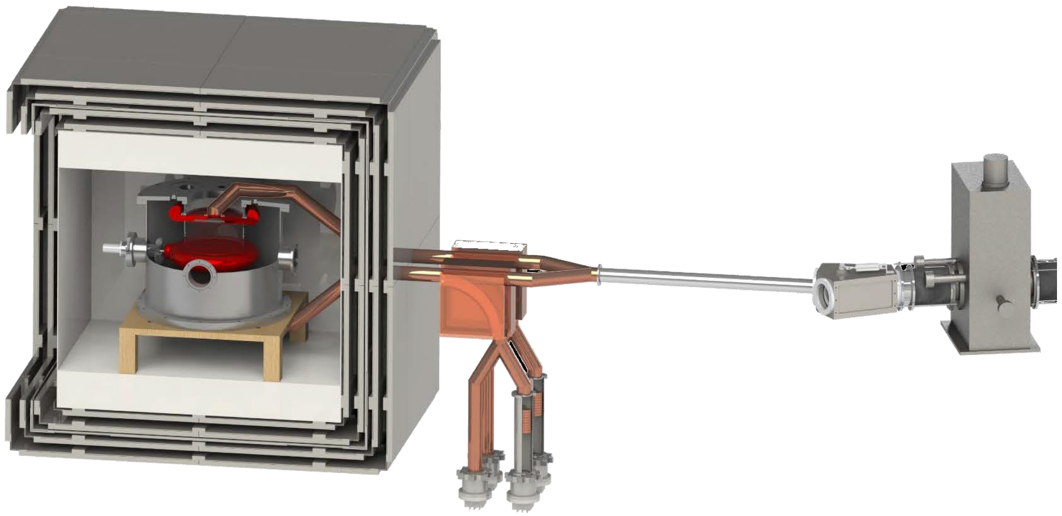
- Major milestone achieved: First UCN produced at TRIUMF
- Source upgrade under way, operational 2021
- Will enable nEDM measurement with 10^{-27} *e*cm sensitivity
- High-intensity source for high-precision UCN experiments
  - Neutron lifetime
  - Gravity at short ranges
  - Decay correlations
  - Exotic decay channels
  - …

TRIUMF

Thank you for your attention!

Wolfgang Schreyer for the TUCAN collaboration

Statistical sensitivity of 10^{-27} *e*cm reached after ~300 beam days



Many effects taken into account

- E = 12 kV/cm
- α_0 = 0.95, α_f = 0.6
- T_1 = 1000 s, T_2 = 500 s
- T = 120 s, τ = 130 s
- Guide transmission 90%/m
- N_0 = 300/cm^3, N_f = 200/cm^3
- V_{cell} = 16 L
- Measurement time per beam day: 16 h
- Beam days per year: 200